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AN EXPERIMENTAL INVESTIGATION AND PERFORMANCE ASSESSMENT OF A SOLAR WATER PURIFIER

G. VIVEK BHARADWAJ, Dr. B. C. ASHOK, Dr. S. A. MOHAN KRISHNA
N. JAYASHANKAR & ARUN. C. DIXIT

Department of Mechanical Engineeringg, Vidyavardhaka College of Engineering, Mysuru, India

ABSTRACT

Drinking water is the most rapidly depleting resource on the earth. But it is also the one, which is taken for granted by most of the population. So to make sure that the future generations can enjoy the life on earth instead of waging war over water, new methods should be developed to solve the water crisis. In this project, a method of using renewable energy sources and environmental friendly processes to build a water purification unit is employed. A model of the system is built and is tested for various parameters to access its performance. On the basis of the obtained results, a design for a self-operating solar water purification product is proposed, i. e. with a few comprehensive studies, this system can be marketed. The advantage of this system is that it uses only gravitational force and solar energy to operate. And only periodic supervision and maintenance is required.

KEYWORDS: Drinking Water, Water Purification Unit & Solar Water Purifier

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Original Article

INTRODUCTION

Water is the most fundamental requirement for all living beings. Due to over population and rapidly changing climatic conditions, fresh water availability on this planet is reducing every year. Even the available water sources are being contaminated by human activities. More than 1.2 billion people around the world lack access to clean drinking water[1]According to the World Health Organization, waterborne diseases account for an estimated 1.5 million human deaths annually.[2] Another major concern of water portability is heavy metal poisoning. Heavy metal poisoning is a medical condition that occurs due to elevated levels of heavy metals like Iron, arsenic, fluoride etc. in the body.

The most promising solution for this problem is Solar Disinfection (SODIS). It is the technique of placing water in transparent plastic or glass containers which are then exposed to sunlight. Its germicidal effect is based on the combined effect of thermal heating of solar light and UV radiation. SODIS method is recommended for treating drinking water at domestic level. Moreover disinfected water by SODIS is free from any hazard as it is free from toxic elements. At a water temperature of about 30 °C (86 °F), a threshold solar irradiance of at least 500 W/m2 (all spectral light) is required for about 5 hours for SODIS to be efficient. This dose contains energy of 555 W/m2 in the range of UV-A and violet light, 350–450 nm, corresponding to about 6 hours of mid-latitude (European) midday summer sunshine.[4] At water temperatures higher than 45 °C (113 °F), synergistic effects of UV radiation and temperature further enhance the disinfection efficiency. Above 50 °C (122 °F), the bacterial count drops three times faster.[4] If the irradiation is very less due to clouds, the water can be exposed for a longer time. For irradiation between 200 to 400W/m2, exposure time of 8–10 hours will be effective.

LITERATURE SURVEY

Water Purification and Disinfection by using Solar Energy: Towards Green Energy Challenge by Md. Z. H. Khan, et al

Study has shown that SODIS is effective in reducing diarrheal illness in children when implemented in field trials. The study shows that treatment of water with any of the possible options available for SODIS results in higher removal of bacteria and bacterio phages than treatment of tap water with the other options.

Field Comparison of Solar Water Disinfection (SODIS) Efficacy Between Glass And Polyethylene Terephalate (PET) Plastic Bottles Under Sub-Saharan Weather Condition. By J. K. Asiimwe, B. Quilty, C. K. Muyanja and K. G. McGuigan

In this study, a comparison of SODIS efficacy using glass and plastic polyethyleneterephalate (PET) bottles was carried out under strong real sunlight and overcast weather conditions. Both clear and turbid natural water samples from shallow wells and open dug wells, respectively, were used. The studies reveal no significant difference in SODIS inactivation between glass and PET bottles, for all water samples under the different weather conditions except for clear water under overcast conditions where there was a small but significant difference with less viable bacterial counts in PET bottles at two intermediate time points but not at the end of the exposure. The results demonstrate that SODIS efficacy in glass under tropical field conditions is comparable to PET plastic.

Feasibility of Solar Energy In Disinfection of Water Source for an Indian Village. By Satya Narain, Abebe. A. K., Chaube. U. C., Mishra S. K

In this study, SODIS technique is used to inactivate microbes in an Indian village Roorkee. Energy from the sun is available abundantly in a tropical country like India. So its feasibility is studied using the water from the nearby river. The overall efficiency of the SODIS under this study reduces the concentration of total coli form from high risk concentration to low risk concentration. The result of the experiment shows that there is a reduction in the total coli form (79.2%), TDS (41.03%) and EC (40.67%) after exposing the sample for 8 hours (one day) on sunlight.

PROBLEM STATEMENT

Currently, the available systems for water purification either focus on removing the metal impurities or they only focus on the removal of bacterial impurities. There is no easy and cost effective system which can remove both bacterial and metal impurities.

So the objective of this study is to combine the available systems and to make necessary changes so that the obtained system will remove both metal and bacterial impurities in a cost effective and efficient manner. It also has to have the added advantage of using renewable energy sources so it can be used by the people who live away from any kind of power grid or the water supply chain.

EXPERIMENTATION

The proposed design of a solar water purifier has the following subsystems as shown in figure 1:

- Compact sand filter: The compact sand filter is used to remove the suspended particles and some of the dissolved components so that the turbidity of the water can be reduced. The output of the compact sand filter is sent to the adsorption chamber.

- Adsorption chamber: The adsorption chamber is provided with some kind of adsorbent which has micro or nanotubes through which the partly filtered water passes through. By doing so the metal impurities are filtered out and the output of this unit will be fed to the SODIS unit. The type of adsorbent has to be selected after a comprehensive study of many parameters of different adsorbents.
- SODIS unit: It is a biological filtration unit where the filtered water is exposed to sunlight. For this, simple PET bottles or a water collector can be used.

The sand filter used is a rapid sand filter with 3 layers consisting of Fine sand, Coarse sand and Gravel with grain size less than 1 mm, 1 mm to 5 mm and 2cm to 4 cm respectively as shown figure 2. The design is such that the Gravel and sand layers are in the ratio of 2:3 and the ratio of coarse sand layer to fine sand layer is 1:3.[5][6] The sand filter designed accordingly is of depth 20 cm with water head of 10-12cm above it to ensure proper flow. Mesh is provided between the layers of sand and gravel. The depth of layers are of fine sand, coarse sand and gravel are 90 mm, 30 mm and 80 mm respectively.

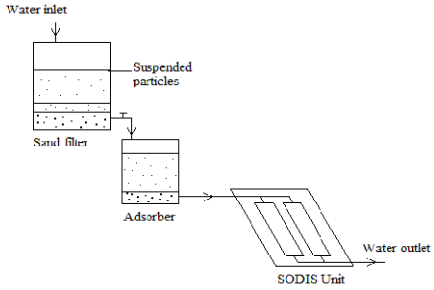

Figure 1: Experimental Setup.

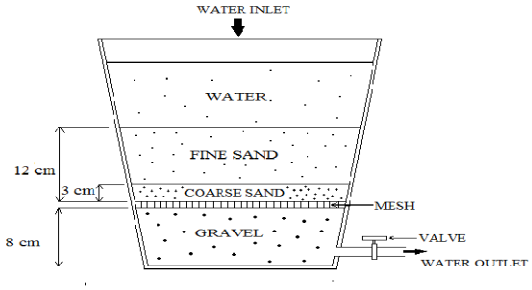

Figure 2: Sand Filter.

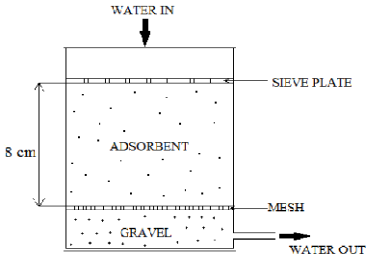

Figure 3: Adsorbtion Chamber.

To ensure optimal results, the adsorption has to take place through a depth of 8 cm with slow or medium slow rate. [11] A sieve plate is fitted above the adsorbents such that water is not directed at the same position throughout the process. The flow rate to this chamber has to be controlled because the nominal flow rate for adsorption of metals is less than 0.2 l pm for fresh water adsorption. Activated carbon and zeolite were selected as absorbents because of their easy availability and easy disposal. So as part of the experiment, performance study of different compositions of activated carbon and zeolite are also done and details are provided in table 1. The adsorbent is supported by a layer of gravel. They are separated by a mesh. It helps in avoiding adsorbent from sinking downwards. The setup details are provided in figure 3.

SODIS study is carried out by using a PET bottle for exposing the water by an inclination stand that will allow us to adjust the inclination of the bottle in the current study PET bottle is inclined at 45°.

A model was constructed to study the performance of the system. The model was built mostly using the items found in the household, so that this system can be built in remote areas for domestic use with little resources. All the systems explained earlier are built and are connected using plastic tubes. To control the flow of water, flow control valve is located at inlet and outlet of adsorption unit. The dimensions and other particulars of the model are given in the table 2 and the setup is shown in figure 4.

Table 1: Details of Properties of Adsorbent

Sl No.	Particulars	Activated Carbon(Grade I)	Zeolite
1	Density (kg/m3)	750	900
2	Porosity (nm)	2–5	0.53–0.56
3	Surface Area (m2/g)	1800	1200

Table 2: Details of Dimension of the Model

Sl No.	Particular	Value
1	Mean Diameter of the Sand filter	28 cm
2	Height of the Sand filter	34 cm
3	Adsorption chamber diameter	12 cm
4	Adsorption chamber height	15 cm
5	PET bottle diameter	11 cm
6	PET bottle height	34 cm
7	Capacity of the PET bottle	2.25 litres
8	Water Flow rate after the Sand filter (Without Flow control valve)	1.2 lpm
9	Water Flow rate after the Sand filter (With Flow control valve)	0.15 lpm
10	Time taken to fill the PET bottle	21 min
11	Adsorbents Used	Activated Carbon(Grade I) And Zeolite

Figure 4: Experimental Setup.

EXPERIMENTAL PROCEDURE

The water to be purified was collected from Kukkarahallilake and poured into the sand filter then sent to the adsorption chamber through a flow control valve at the rate of 0.15l pm. Water exiting from adsorption unit is stored in PET bottle, which is then exposed to sunlight for the time duration of 4 hrs at an inclination of 45°.

PERFORMANCE STUDY

Performance study of this purifying unit is done by varying the absorbent ratio in different proportions as mentioned in the table 3.

Table 3: Absorbent Ratio details for different Samples

Sample	Activated Carbon (Grade I) (in %)	Zeolite (in %)
Sample no. 1	100	0
Sample no. 2	75	25
Sample no. 3	50	50
Sample no. 4	25	75
Sample no. 5	0	100

RESULTS AND DISCUSSIONS

Water purified from the SODIS unit is tested for different parameters which determine water portability according to BIS standards. Details of BIS standards are given table 4.

Water quality varying with adsorption material composition ratio is analysed on the basis of different parameters with the aid of graphs.

Turbidity

The turbidity of the lake water was **40 NTU**. Permissible limit for turbidity is **10 NTU** and the desirable limit is **5 NTU**. All the samples are in this limit but Samples 3 and 5 are closer to upper limit. Sample 1 has the highest reduction rate of 90%.

Table 4: Details of BIS Standards

Sl No.	Parameter	Desirable Limit	Permissible Limit
1	Total Hardness	300 ppm	600 ppm
2	Iron	0.3 ppm	1.0 ppm
3	Total Nitrates	45 ppm	No relaxation
4	COD	<250 ppm	No relaxation
5	Turbidity	5 NTU	10 NTU
6	BOD	<5 ppm	No relaxation
7	E. coli	<1ppm (i. e non detectable)	No relaxation

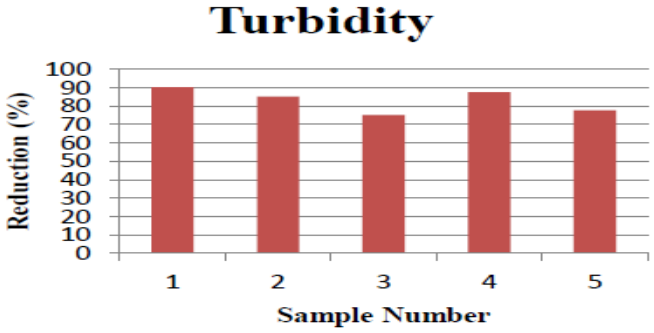

Figure 5: Graph Showing Percentage Reduction Rates of Turbidity.

Iron as Fe

The Iron content in the lake water was **4.7 mg/l**. All the samples except Sample no. 3 are within the desirable limit. Sample no. 3 has Iron content more than others but it is well within the permissible limit. Samples 4 and 5 have the highest reduction rate of 97.23%.

Total Hardness

The total hardness in the lake water was **170 ppm**. Desirable limit is **300 ppm**. So the lake water is already within desirable limits. Sample 4 has the highest reduction rate of 45.88%.

Total Nitrates

The amount of total nitrates present in the lake water was **23.19 ppm**. It is within the desired limits of **45 ppm**. The nitrate levels in the water samples except Sample no. 4 increased. But nitrate values in all the samples are well within the desirable limits. This increase in the nitrates may be due to the nitrates released from the sand or the adsorbents in the filters. This can happen due to the nitrate content in the sand and agitation caused during filtration. Since Sample 4 is the only one that shows reduction, it has the highest reduction rate.

Chemical Oxygen Demand (COD)

COD is the measure of the amount of oxygen that can be consumed by reactions in a measured solution. The COD of the lake water was **67 mg/l**. It is already less than the desirable **250 mg/l**. The highest reduction rate was 82.08% and it was seen in Samples 2 and 4.

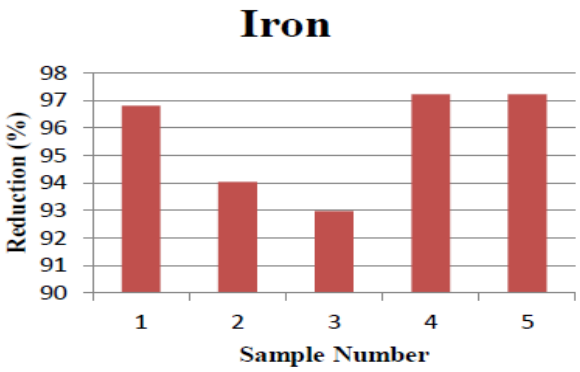

Figure 6: Graph Showing Percentage Reduction Rates of Iron Content.

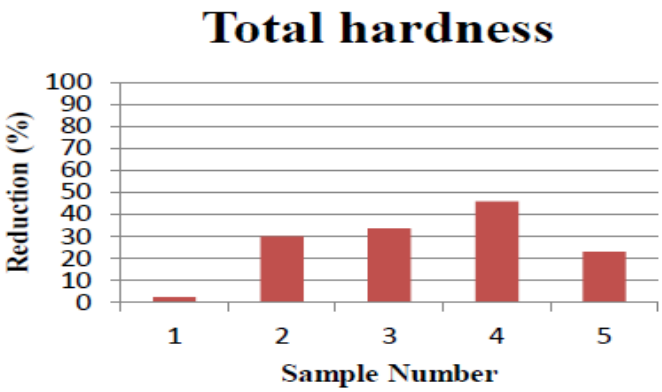

Figure 7: Graph Showing Percentage Reduction Rates of Total Hardness.

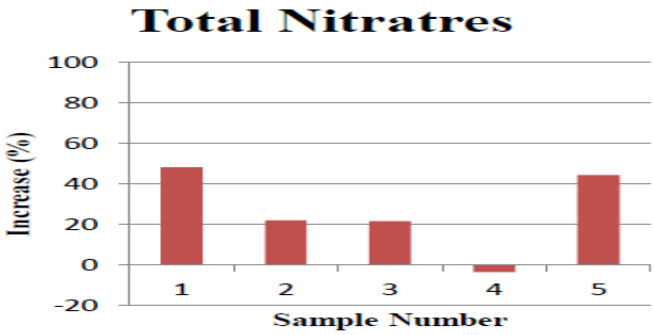

Figure 8: Graph Showing Percentage Reduction Rates of Total Nitratres.

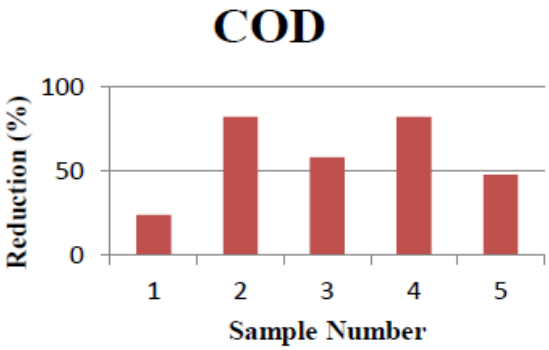

Figure 9: Graph Showing Percentage Reduction Rates of COD.

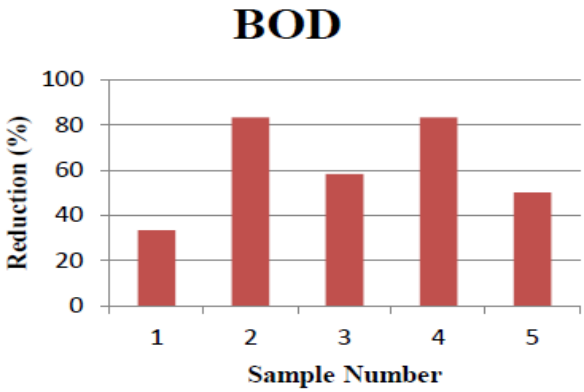

Figure 10: Graph Showing Percentage Reduction Rates of BOD.

Biological Oxygen Demand (BOD)

BOD of the lake water was **12 mg/l**. The Desirable limit of BOD is **5 mg/l**. All the samples except sample no. 1 and 5 are under this limit. This may be caused due to the variation in solar irradiation or due to contamination of the water sample while it was being handled. Highest reduction rate is 83.3% which was seen in Sample no. 2 and 4.

Escherichia Coli

E. coli is a bacteria that is predominately present in sewage water. The lake sample collected has <1 ppm of E. coli in it. So all the Samples show <1 ppm in their E. coli test that means the presence of E. coli in the samples are undetectable.

BOD Varying Against Solar Irradiation

From the graph shown in figure 11 it is seen that BOD varies inversely to the solar irradiation. From this we can infer that as solar irradiation increases the value of BOD decreases in the sample water.

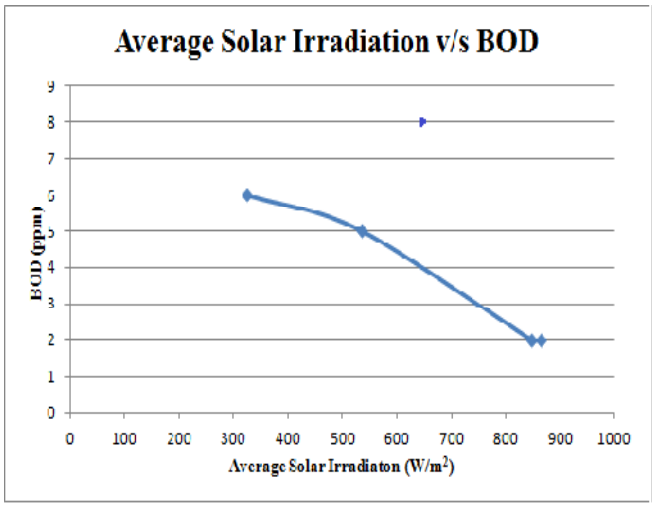

Figure 11: BOD Vs Solar Irradiation.

CONCLUSIONS

Sample No. 4 of adsorbent composition has the best results in most of those parameters which includes reduction of nitrates primarily. The BOD reduction is done by exposing sample into solar irradiation. Reduction percentage of vital parameters of water sample is tabulated in table 5. The water comparison before treating to solar water purifier and post purification is shown in figure 12

Table 12: Sample 4 Parameters Reduction

Sl No.	Parameter	Percentage Reduction
1	Turbidity	87.5
2	Iron as Fe	97.23
3	Total Hardness	45.88
4	Total Nitrates	3.62
5	COD	82.08
6	BOD	83.3

Figure 12: Comparison of Purified Water with Aid of SODIS and unpurified Water.

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AUTHORS PROFILE

DR. ASHOK B.C is a graduate from N.I.E, Mysore under Mysore University, M.Tech in Maintenance Engineering and Ph.D under V.T.U, Belguam. His research interests are Maintenance and Production Management.He has handled subjects like Dynamics of Machinery, Kinematics of Machines, Vibrations, Control Engineering, Mechatronics, Metrology and Measurements, Project Management, Total Quality Management, Computer Aided Engineering Drawing.He has guided about 25 projects. He is the coordinator of EMS program, timetable and member of anti- ragging committee. He is a life time member of Indian Society for Technical Education (ISTE) and Indian Institution of Production Engineers (IIPE).He has published/presented in one International journal, one National journal, two International conference and three National conferences.

Rtn. Dr. S A Mohan Krishna completed Bachelor of Engineering from one of the prestigious institutions in Mysuru, Vidyavardhaka College of Engineering (VVCE) in 2003, M. Tech in Energy Systems from Sri Jayachamarajedra College of Engineering (SJCE), Mysuru in 2010 and completed Ph. D at The National Institute of Engineering (NIE), Mysuru in 2017 on 'Thermal Characterization Techniques of Materials' belonging to the area of thermal engineering and

computational materials science. His area of interest in teaching and research is mainly Thermal Engineering. He teaches the prominent thermal engineering subjects namely, Basic and Applied Thermodynamics, Turbomachines, Energy & Environment, Heat & Mass Transfer, Cryogenics, Energy Engineering, Power Plant Engineering, Non-Conventional Energy Sources, Computational Fluid Dynamics, Fluid Mechanics, and Automotive Engineering. Has published over 70 papers in peer reviewed international journals and has presented papers at Qatar and Singapore and also in various parts of Karnataka. He is in the editorial and reviewer board for over 35 reputed referred international journals including the most prominent namely Elsevier and Springer. Earlier, he has authored two text books in the stream of engineering with the title, A Text Book on Cryogenics and A book on Illustrative Problems in Engineering Thermodynamics. He is also a research supervisor and is currently guiding three research scholars.

He is a life member and member for Indian Society for Technical Education (ISTE), Institution of Engineers (IoE), Society of Automotive Engineers (SAE), and Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE). He is also associated with Indian Cryogenic Council and Association of Ammonia Refrigeration. Apart from the profession, he is a recognized observational astronomer and freelance science writer. He is keenly associated with International Astronomical Union, Paris, Astronomical Society of India, Breakthrough Science Society, Karnataka RajyaVignanaParishat (KRVP), Mysore Science Foundation, Indian Academy of Sciences, Materials Society, Combustion Society, Green Building Association, Bangalore Association of Science Education (BASE), Numismatics Society, Rotary Foundation and many other science societies and service oriented associations in popularizing and communicating Physics, Astronomy and Astrophysics, Cosmology, Social Service, Outreach and essence of engineering. His hobbies include astrophotography, numismatics, outreach activities, observational astronomy, and science communication & popularization. Has been given two awards in the field of engineering and technology.

Prof N Jayashankar has done his Bachelor of Engineering in Mechanical Engineering from SJCE Mysore (Mysore University) and Master of Technology Master of Engineering Management (MEM) from SJCE Mysore He started his career at BEML and later teaching at NIE. At present he is Assistant Professor at VVCE with 14 years of teaching experience. His working areas include Fluid Mechanics, Project Management and Management Information system. He is a life time member of Indian Society of technical Education. At college level he has worked in various committees and presently a member Library committee.

G VivekBharadwaj as a Master of Technology in Thermal Power Engineering, **VTU Belagaum**, completed in 2015(69.3% FC) and Bachelor of Engineering in Mechanical Engineering, **VTUBelagaum**, India, Completed in 2012(58.5% SC)

Arun C Dixit, working as an assistant professor in the Department of Mechanical Engineering at Vidyavardhaka College of Engineering. BE, M.Tech and pursuing Ph. D in Machine Design. Ha over 30 research publications.